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Federal Aviation Administration

Advisory Circular

Subject: ENERGY CONSERVATION FOR AIRPORT BUILDINGS

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1. PURPOSE. This advisory circular (AC) provides guidance for promoting energy conservation in the design and operation of airport buildings; for initiating energy conservation programs; and for conducting airport building energy assessments.

2. BACKGROUND.

a. The Energy Policy and Conservation Act (EPCA), Public Law (P.L. 94-163), signed by the President on December 22, 1975, was designed to promote energy conservation in all national sectors.

b. The Powerplant and Industrial Fuel Use Act of 1978, P.L. 95-620, directed the President to require each Federal agency authorized to extend financial assistance by grant, loan, contract, or otherwise to act promptly to maximize the efficient use of energy and the conservation of petroleum and natural gas in Federally funded programs.

c. Executive Order 12185, which implemented P.L. 95-620, instructed Federal agencies to identify those financial assistance programs that are most likely to offer opportunities for significant conservation of petroleum and natural gas. Agencies administering programs so identified were instructed to take actions necessary to achieve energy conservation in those programs. The Airport Improvement Program (AIP) which provides financial assistance for airport development and improvement projects is one such identified program.

3. RELATED READING MATERIAL. Appendix 1 contains a listing of publications containing supplemental material relating to energy conservation in buildings. Ordering information, where available, has been included.

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CHAPTER 1. GENERAL

1. INTRODUCTION. In the past, building designers and airport operators placed a low priority on the efficient use of energy in airport buildings as energy was relatively cheap. As a result, airport buildings wasted considerable energy. This state of affairs is no longer acceptable. It behooves designers to make energy conservation a prime objective in designing and remodeling airport buildings. And it behooves airport operators to make energy efficiency a high priority in day-to-day management of building operations and maintenance.

2. SCOPE. This AC was developed to provide guidance for promoting energy conservation in the design and operation of airport buildings. It is not intended to replace the technical manuals and textbooks (a number of which are listed in this AC) that provide detailed instructions and sample calculations to assist in energy conservation design and building management. Rather, it is intended to alert building designers and airport/airline operators as to what can and should be done to assure that airport buildings are designed and operated in an efficient manner and to suggest some areas where energy waste can be eliminated.

3. ENERGY CONSUMPTION DEFINED. In this AC, the term "energy consumption" is limited to energy usage within the building envelope. Except in the case of solar energy, this usage is directly reflected in the monthly utility bill of the airport and thus is the most appropriate frame of reference for the purposes of this discussion. It is necessary to state this definition since energy consumption can be calculated from different sets of boundaries. For example, coal, oil, and gas are raw fuels commonly converted to heat by onsite combustion. The efficiency of this conversion can be accounted for in considering a building energy conservation program. Electricity, on the other hand, is a secondary source and, typically, raw fuel conversion for production of electricity takes place offsite. The losses of this conversion are hidden from view but are high--65 to 75 percent of the raw fuel burned. If reference boundaries are expanded even further, energy losses incurred in mining, drilling, pumping, refining, and distribution of new fuels to the consumer can be included in the assessment. Although these enlarged boundaries might be appropriate for studies involving national policy considerations, they are of little value to the airport operator or designer.

4. ENERGY EQUIVALENTS. In making an energy consumption assessment of an airport building, or any building for that matter, it is convenient to reduce various energy usage components to a common equivalent such as the British Thermal Unit (Btu). In this way, total building energy consumption can be arrived at by summing the equivalents of the various energy sources. This total divided by the gross building area yields energy usage in Btu's per square foot, a very valuable unit for comparing building performance from an energy standpoint. For convenience, table 1 provides some common energy equivalent conversions.

Table 1. Energy Equivalents.

No. 2 oil	138,000 Btu/gal
No. 6 oil	146,000 Btu/gal
Natural gas	1,000 Btu/ft^3
Manufactured gas	800 Btu/ft^3
Coal	26,000,000 Btu/short ton
Steam	900 Btu/lb
Propane gas	21,500 Btu/lb
Electricity	3,413 Btu/kWh

5. ENERGY USAGE BY BUILDING SYSTEMS. Within the building envelope, energy is consumed for various functions: heating, cooling, lighting, power for equipment, and heating for domestic hot water. The order of magnitude for these variables will differ in any building with climate, with building function, and with individual characteristics involving building systems design, construction, and operation. The actual energy consumed by a building in any one of these categories is dependent on a complex of operating procedures, equipment performance, and functional requirements, each of which is a variable.

6. ENERGY LOADS. For the purpose of managing energy flows within buildings, it is useful to classify energy usage in terms of building, distribution and conversion loads.

a. Building Loads. Building loads consist of all energy consumed for the environmental control of temperature, humidity and ventilation within a building; for lighting; and for operating equipment such as elevators, computers, and coffee pots. In other words, it is the amount of energy in Btu's or kilowatt hours consumed to maintain desired indoor space conditions and to operate building equipment, independent of losses occurred in distributing and converting the energy. Thus, only end-use consumption is considered. The magnitude of a building energy load is dependent on the following conditions:

(1) Location. The location and orientation of the building affects the heating and cooling loads, since the amount of solar radiation which strikes the building's exterior surfaces determines the solar heat gain at any period of the year. The amount of sunshine entering the building through openings will also affect the amount of artificial illumination required.

(2) Climate. The major climatic conditions which affect the amount of energy consumed for heating and cooling are: temperature, humidity, and air movement.

(3) Degree of Environmental Control and Process Loads. The degree and length of time that indoor conditions (such as temperature, humidity, ventilation, quantity and temperature of hot water, lighting levels, etc.) are maintained affect the size of the building load. Also, energy usage for processing loads such as the operation of elevators, escalators, reservation computers, communications equipment, cooking and refrigeration equipment, etc., is dependent on the period of time used. Equipment (e.g., computers, cooking ranges, etc.) that emit heat also affects a building's heating and cooling loads.

(4) Number of Occupants and Period of Occupancy. The number of occupants (employees, passengers, and visitors) in the building will affect the degree of environmental control and processing/equipment loads which, in turn, affects the overall building energy load. Peaking of passenger activities during short periods of time versus widely spread scheduling distribution will impart building loads of differing magnitudes.

(5) Thermal Performance of Building Structure. The amount of heat conduction and leakage through the building envelope and the infiltration of outdoor air are dependent on the thermal and structural properties of the building and have a significant affect on the building heating and cooling loads.

b. Distribution Loads. It takes energy to move energy. Distribution loads (often characterized as parasitic loads) are inevitable in the best of cooling, heating, and electrical distribution systems. Energy is expended to operate fans and to operate pumps for hot, chilled, or condenser water. Additional loads are caused by fluid leakage or unwanted heat transfer in the heating and cooling duct and piping systems. In electrical systems, there will be some loss through transformers and in the resistance of conductors and switchgear.

c. Conversion Loads. Energy to satisfy the heating and cooling load is moved typically through a distribution system from prime conversion hardware, namely, boiler, furnace, or refrigeration equipment. The gross energy consumption for the heating and cooling building load and the distribution load is dependent on the efficiency of the primary conversion equipment. Any improvement in the efficiency of combustion or in refrigeration heat will translate directly into energy savings.

7. ANNUAL ENERGY AND PEAK ENERGY REQUIREMENTS.

a. Annual energy consumption in any particular building is not a fixed quantity. It depends not only on the design of the building and its systems, but also on the mode of operation and the quality of maintenance. Efficient operation and maintenance modes can easily cut energy consumption by 50 percent or more.

b. Annual energy consumption determines the fuel bill, but peak energy demand defines the scale and the first cost of the equipment that serves the building. As energy costs have risen, so has the importance of considering life-cycle costs of energy-consuming equipment and not merely the initial capital cost.

c. Many, if not most, of the measures related to energy-conscious design will reduce peak loading requirements and capital costs as well. With an electrical system, peak demand is a part of the billing. Consequently, reduction of peak demand saves dollars directly. It is untrue that a building owner must invariably pay more now to save later. Good design of new buildings should enable reduction in both capital and energy costs.

d. Both peak load and annual energy demand for new and old buildings alike are amenable to calculation, though annual energy usage estimates are subject to greater error in new buildings due to the difficulty in forecasting two major variables, namely, the mode of operations and the quality of maintenance. Peak-load estimates for the purpose of sizing equipment are common in routine design methodologies. Annual usage estimates are less common but are increasingly required for design decisions involving life-cycle costs. In the future, such estimates may be required by many jurisdictions as a measure of compliance with energy conservation codes.

e. Peak load estimates can be computed manually with a given set of steady state conditions--usually maximum and minimum expected conditions outdoors and occupied conditions indoors, including lighting levels and equipment operations. While these calculations give a reasonable indication of the size of equipment needed to meet maximum loads (invariably conservative), they give no indication of energy demands to meet the myriad part-load conditions that actually occur in an average year. A rough analysis of yearly energy consumption can be obtained by using heating degree-days and cooling degree-hours, but such an analysis totally ignores the building and system reactions to constantly changing conditions, such as internal heat gain, solar radiation, and wind effects.

f. Closer approximations of yearly energy consumption can be obtained by making a series of calculations for different outdoor conditions during both occupied and unoccupied times and correcting for the length of time these conditions are expected to exist. The accuracy of the results improves with the number of different conditions selected and the number of separate calculations. However, such a procedures can develop into a long, tedious, and costly process if done by hand.

8. COMPUTER MODELING. Computers are extremely good at making a series of repetitive calculations, and programs have been developed independently by many organizations to perform energy calculations. Because these programs have been developed independently, each one has characteristics and functions which are unique. One program, for instance, may be very good at calculating heating and cooling loads but rather crude in its approach to analyzing heat/ventilation/air-conditioning (HVAC) system reaction to these loads. Another may carefully analyze interreaction between HVAC systems but base its building-load calculations on extrapolations of one typical day or month. Calculation programs fall into two categories: those used for solving load design problems and those used for calculating energy usage. There is some overlap between categories as some of the later programs have subroutines which can be used independently for design problems.

a. Design Programs. Computer programs have been developed to allow rapid solution of particular design problems such as pressure drop in piping and ductwork systems. They are valuable since they allow more alternative schemes to be considered in the initial design stages than would be possible with hand calculations. Thus, they increase the options available to the designer in choosing the most energy-efficient heating, cooling, lighting, sytems, etc. Some programs for equipment selection, however, must be used with discretion as they only recognize certain makes of equipment and will not necessarily allow selective comparisons to be made.

b. Energy Usage Programs. Energy usage programs have been developed to calculate the yearly energy demands for buildings and systems combined, for buildings alone, or for systems only. Smaller programs or parts of larger programs are also available to calculate yearly energy demands for discrete portions of a building or for a particular system considered in isolation. Most of these programs are designed to first calculate the building and/or system loads for a given set of conditions and then simulate the operation of the building and/or systems to determine their reaction to continuously changing conditions.

c. Available Computer Programs. Appendix 2 contains a listing of available computer programs that may be useful for energy design and for evaluating systems. These lists are assembled from various sources and are not necessarily complete; neither are they an indication of equal quality and performance. When selecting programs for a particular application, prospective users should obtain detailed information from the program authors and then make their own evaluations based on their requirements, inhouse computer capabilities, and projected costs.

CHAPTER 2. ENERGY MANAGEMENT PROGRAM

9. GENERAL. This chapter provides guidance for initiating and implementing an energy management program for airport buildings. A major element of such a program is an energy assessment of the building's systems, including operational and maintenance procedures. Such an assessment, however, will be worthless if not actively supported and pursued by airport management as well as all major tenants and airport employees. A primary objective of an energy management program, therefore, is to establish the means, be it through formal committee structure or other administrative actions, to stimulate an awareness of the recommended energy conservation measures and to create the cooperative spirit necessary to implement them.

10. OBJECTIVES OF AN ENERGY MANAGEMENT PROGRAM. The objectives of an energy management program for an airport building are threefold; namely:

a. To minimize the energy consumed for heating, cooling, lighting, and other building services and thus reduce annual building operating costs.

b. To use the particular type of fuel or electricity which is available at the lowest cost (and to switch from one fuel to another if the relative cost changes radically in the future); and

c. To carry out those objectives within the financial capability of the airport operator and tenants.

11. ENERGY MANAGEMENT GOALS. Studies have shown that the establishment of an energy management program at an airport can result in a reduction 15 to 35 percent in total annual energy consumption at the facility measured against those for the previous year. For example, in a large hub airport with annual energy costs of $2 million, a very conservative estimate of potential savings would be $400,000 a year. To achieve the higher limits of potential savings will require some capital expenditures. Below is a probable breakdown of potential savings on the basis of capital outlays that was developed in a study sponsored by the Air Transport Association of American (ATA).

a. Savings which can be realized with little or no capital outlay will probably represent 30 to 50 percent of the total possible savings.

b. Savings which require no further study and which will return the required capital investment within a 5-year period will probably represent 20 to 25 percent of the total possible savings.

c. The balance of the savings will require detailed energy analysis and up to a 5-year period for capital investment return.

12. ESTABLISHMENT OF AN AIRPORT ENERGY COMMITTEE. In order to execute a successful energy management program, airport management must have the active support, cooperation, and participation of the airlines, concessionaires, and other airport tenants. For this reason, it is highly recommended that an Airport Energy Committee (AEC) be established at each airport. This committee should normally be comprised of representatives from the engineering, maintenance, and/or operations staffs of the airport operator, the airlines, fixed-base operators, and major

concessionaires/tenants. The airport manager or representative should generally be the chairperson of the committee although a representative from a major tenant airline might be selected for this position or serve as deputy or co-chairperson.

13. COMMITTEE RESPONSIBILITIES. The responsibilities of the AEC will vary from airport to airport depending on the particular circumstances at each locality. These responsibilities and its charter and authority should be established early in its existence. Suggested responsibilities include the following:

a. Establish energy management goals and objectives for the airport;

b. Provide liaison between airport management and the airlines as well as other airport tenants;

c. Develop guidelines for conducting an energy survey and assessment and for implementing an energy management program;

d. Supervise the conduct of an energy management program, including selection of a study team;

e. Assist in the acquisition of survey data;

f. Review energy evaluation study findings, including proposed systems and operational changes;

g. Made recommendations to airport management and airline committees;

h. Oversee the implementation of energy management proposals;

i. Initiate employee awareness programs and enlist employee support and participation; and

j. Monitor the program's accomplishments--which might involve establishing uniform recordkeeping and reporting requirements.

14. SELECTION OF PROGRAM GOALS. The establishment and implementation of an airport energy management program can have a number of goals, the choice of which can have a significant effect on the design of the program. These goals should be determined by the AEC before proceeding with program actions. These goals can be kept very general as depicted in the following examples or be made very specific and quantitative.

a. Primary Goals.

(1) Reduce energy consumption as much as possible without incurring initial capital costs through more efficient operations/maintenance.

(2) Reduce operating costs through installation or retrofit of more energy efficient equipment, e.g., boilers, air conditioners, and material, e.g., double-glazed windows, insulation, etc.

(3) Reduce the likelihood of shutdown due to reduced voltage or curtailment of power or fuel supplies.

(4) Meet existing Federal, state and local energy conservation guidelines and standards.

b. Secondary Goals.

(1) Extend the life of the mechanical and electrical equipment to reduce the frequency of equipment breakdown and replacement costs.

(2) Improve the performance of service and maintenance personnel to reduce operating costs and equipment failure.

(3) Reduce airborne pollution.

(4) Enhance the rentability of the building through lower operating costs.

(5) Improve the internal environment by reducing disturbing glare from lighting and/or eliminating drafts from infiltration of cold air through wall surfaces.

15. INITIATION OF ENERGY ASSESSMENT STUDY. Based on the desired objectives, an energy assessment study should be designed and undertaken. Such a study can be carried out by a team selected from airport/airline staff personnel or by a professional architectural/engineering firm. This choice will depend on the selected goals and objectives of the program and the size and complexity of the airport building system. If an architect/engineering firm is solicited, it should be one experienced in energy evaluation and management.

16. COMPONENTS OF ENERGY STUDY. An energy assessment study can be very simple or very complex, depending on how much effort management wants to put into it and what objectives are desired. The following components are recommended for most formalized energy assessment studies.

a. Climate Profile. The climatic conditions to which the building is exposed over extended periods of time should be identified. Climatic maps are very helpful in this regard and provide information that is useful for energy calculations in evaluating various building systems. These maps provide a broad general picture of climatic conditions in any particular area. They do not contain micro-climate information or local weather variations. More precise data for major cities can be obtained from published weather/climate data or from local weather reporting stations. Below are listed two types of data that are very useful in developing a climate profile:

(1) Annual Heating Degree Days. Heating Degree-Days influence the annual energy consumption for building heating loads. A Heating Degree-Day is an average temperature 1° below a 65°F temperature base. The number of Heating-Degree Days in a particular 24-hour day is determined by subtracting the average of the high and low temperatures of that day from 65. For example, if the average temperature is 57° for a 24-hour period, this equates to 8 Heating-Degree Days.

(2) Annual Mean Daily Solar Radiation. Solar radiation (measured in langleys) influences the annual energy consumption for the building cooling load by increasing heat gain by radiation through windows and doors and by conduction through roofs and exterior wall surfaces. Solar heat gain also reduces building heating loads in the winter.

b. Building Plan, Condition, and Use Survey. A thorough survey of the site and building plans should be conducted to determine actual or planned dimensions, orientation, building configuration, construction materials, and in the case of existing structures, physical condition, notable deficiencies (leaks, missing insulation, etc.), and amount of shading (from buildings, plantings, solar devices, etc.). In addition, data on the applicable building codes, occupancy, type and duration of activities in each specific area of the building, ventilation rates, probable infiltration rates, and appliances or processes which use electricity or emit heat should be collected as part of this survey.

c. Electrical and Mechanical Systems Profile. This involves a survey of existing lighting, power, heating, ventilating, air conditioning, and domestic hot water systems. The operating characteristics, physical condition, control sequences, equipment materials, etc., should be noted. If practical, make the appropriate tests to consider the operating efficiencies of the various mechanical/electrical systems and determine whether adjusting and balancing of the systems are required.

d. Energy Consumption Audit. For existing buildings, determine from monthly utility and fuel suppliers' bills the annual usage of energy in terms of gallons of oil, cubic feet of gas, tons of coal, kilowatt hours of electricity, etc. These totals should be converted to equivalent energy in Btu's and broken down into the individual mechanical and electrical systems and subsystems. For new building design, data from the above surveys should be used to calculate peak and annual heating, ventilating, cooling, and equipment loads for the climatic conditions anticipated and the design indoor temperature and humidity levels.

e. Analysis of Energy Conservation Opportunities. After consideration of all various possibilities for energy conservation with respect to building site, configuration, floor plans, materials, distribution and conversion loads, electrical/mechanical systems, alternative energy sources, etc., select the most promising conservation opportunities and determine the potential annual savings for each option, both singularly and in combination with others. The analysis should consider capital expenditures required and provide payback comparisons for each opportunity considered. Examples and suggestions for energy conservation opportunities are discussed in chapter 3.

f. Energy Assessment Report. The energy assessment report should include results of the various surveys, energy conservation opportunities considered, estimated costs, calculations of anticipated benefits, and final recommendations. The report should not only address immediate energy conservation improvements but also should speak to procedures for carrying out a continuous monitoring program.

17. IMPLEMENTATION OF ENERGY STUDY FINDINGS. At completion of the study, the AEC should review the report's findings and determine which proposals and recommendations should be implemented. This should be followed by development of an

implementation plan detailing how the various conservation measures are to be implemented; responsibilities of the various organizations and individuals for accomplishing the program; budgeting details for capital expenditures; and time schedules, if appropriate. Depending on the charter of the committee, this document should, in all likelihood, be submitted to airport and airline management (as well as other involved tenants) for approval and implementation.

18. MONITORING. Evaluation of the effectiveness of the energy conservation program can be simplified by instituting a system for recording total energy consumption and costs at the airport. Airport management (or the energy committee) should develop procedures to ensure that energy consumption and costs are monitored and recorded in as much detail as necessary. In addition to indicating the effectiveness of the overall program, detailed consumption and cost records provide a means to monitor each individual system's efficiency and operation. The greater the detail of the recordkeeping, the more effective the monitoring will be.

19. EMPLOYEE AWARENESS PROGRAMS. Without the full cooperation of all airport employees, the effectiveness of any energy conservation program will be greatly diminished. Consequently, an employee awareness program should be initiated in conjunction with and as an integral part of the energy conservation program. Actions directed toward employee awareness should be designed so as to capture the interests of the employees and create a feeling of involvement and participation in overall conservation efforts. Staff newsletters and special employee bulletins are excellent media for conveying information about the program and for following up with news of its implementation and, later, its effectiveness. Posters are another means that can be used to provide reminders of the program and the need for employee cooperation and participation. Employee manuals or educational sessions might also be used to make the objectives of the program clear, indicate proper methods for operating the energy consuming systems at the airport, and explaining the expected roles of the employees in carrying out program objectives.

20. EMPLOYEE/MANAGEMENT TRAINING. Attendance by airport building maintenance employees and management personnel at energy seminars and training courses is desirable and will reap benefits in the form of cost savings far in excess of the costs of such training. The Aviation Facilities Energy Association (formerly the Joint Aviation Industry (AAAE/AOCI/ATA) Facilities Energy Management Task Force) sponsors an Energy Management Action Course and energy seminars that are held periodically and are designed to promote energy conservation for airport buildings and facilities. These and similarly structured courses are highly recommended.

CHAPTER 3. ENERGY CONSERVATION OPPORTUNITIES

21. GENERAL. Every airport and airport building contains a numerous conservation opportunities available to the energy conscious airport manager. Some require major investment while others are available with little cost. This chapter contains a discussion of conservation opportunities that may exist at any given airport. The energy conservation opportunities discussed here are not meant to be all-inclusive however. They are merely illustrative. Note that some measures are applicable only to new building design, while others are equally applicable to both new and existing buildings. In considering the implementation of the opportunities discussed below, it must be kept in mind that there are certain design aspects and requirements of an airport terminal building that should not be downgraded in the name of energy conservation. Processing efficiency, public safety, security, and accessibility to the handicapped are a few examples that come to mind. Application of some of the energy conservation measures discussed in this chapter may conflict with these and other design considerations and must be adjusted accordingly.

SECTION 1. BUILDING SITING AND PHYSICAL DESIGN

22. SITE DEVELOPMENT. The site for a new airport building and the orientation of the building on the site will affect total energy consumption. From an energy standpoint, the selection of the site and its development will involve a series of trade-offs, with local weather conditions having a major influence upon the final design. For instance, a building with a north-south major axis receives more solar radiation than one with an east-west major axis. This can have a very beneficial effect for heating but an adverse effect during the cooling season. In windy locations, the possibilities of using adjacent hills, existing building structures, wooded areas, and so on as windbreaks should be considered in selecting the building location and orientation. If such windbreaks are not available, the preparation of a well-conceived landscaping plan can provide some of the same benefits. The same also holds for locations with long, hot summer seasons where shading is highly desirable.

23. BUILDING CONFIGURATION. The configuration of an airport building can determine in large part the amount of energy consumed. Some examples include:

a. Building Geometry. Spherical or round buildings have less exterior surface than any other building shape for an equal amount of total floor space; hence, they experience less heat gain or loss. For the same reason, square buildings experience less heat gain or loss than rectangular buildings of equal area per floor.

b. Building Height. Tall buildings have proportionately smaller roofs and are less affected by solar gains on that surface than low buildings. On the other hand, they are generally subject to greater wind velocities, a condition which increases infiltration and heat losses. Also, they are less likely to be shaded or protected by surrounding windbreaks and require more mechanical support systems. Low buildings, having a greater roof area in proportion to wall area, require more attention in regard to the roof's thermal characteristics.

c. Zig-Zag Building Shapes. These buildings can be used to reduce energy consumption. For instance, a zig-zag configuration of east and west walls provides self-shading to reduce summer solar loads, acts as a natural windbreak; and can permit low rays (if windows in zig-zag are facing south) to penetrate into the building in the winter to supplement the heating system. By facing the windows north in the zig-zag in a southern location, heat gain is reduced year round, while at the same time, natural lighting and visual views can be available at both east and west facades without the penalty of increased summer heat gains. Note, however, that energy demands due to the additional wall surfaces in the zig-zag form must be weighed against the energy benefits.

d. Stilt-Designed Buildings. Buildings that are elevated on columns or have small first floor areas and large overhanging upper floors increase heat loss and heat gain due to the extra exposed floor surfaces. Locating unheated parking garages on intermediate building levels similarly increases energy consumption due to the additional exposed surfaces.

e. Roof Orientation. In this country, a sloping roof facing south will be subjected to more solar radiation than a roof facing in any other direction. Hence, at locations where cooling loads are significant, select a configuration with minimum south roof and wall exposures. Similarly, in colder climates where heat loss is more significant, select a configuration with minimum north wall and roof exposure.

24. BUILDING PLAN. The plan for an airport terminal building must respond to its functional purpose--namely, processing passengers, luggage, and cargo between landside transportation modes and aircraft and vice versa. Similarly, other airport buildings have specific functional requirements that must be accommodated. Nevertheless, opportunities exist in the design of airport buildings to reduce energy waste and promote efficient energy use without diminishing the functional effectiveness of the building. These include:

a. Corridors, equipment spaces, toilets, and other service areas not requiring close temperature control can be located along exterior walls to act as buffer spaces. In northern climates, locating these areas on the north wall provides insulation benefits against the cold whereas in southern areas locating on the east, west, or south walls provides maximum benefits in limiting heat gain.

b. Grouping spaces that have similar environmental control needs can reduce the extent and complexity of the mechanical system and permit heating, cooling, ventilation, and lighting to be concentrated in areas of intense demand.

c. The use of open-planning design, i.e., where partitions are less than floor-to-ceiling height, in lobby, office and concession areas allows excess heat from interior spaces to transfer to perimeter spaces that are subject to heat loss. It also allows more effective use of lighting fixtures.

d. Where energy can be saved by using natural illumination, the building perimeter can be increased and its interior space proportionately decreased, resulting in various building forms, such as multiple courtyards, atriums, light wells, finger buildings, and low buildings with skylights. Use of natural lighting for energy conservation may be appropriate at locations with exterior conditions close to interior conditions, i.e., where building heat losses or gains are low. However, in cold climates, more energy is conserved by using artificial lighting systems and fewer windows.

e. Locating equipment rooms on the roof reduces unwanted heat gain and heat loss through the roof's surface. It can also allow more direct duct and pipe runs for one- or two-story buildings, thus reducing power requirements.

f. Reducing the number of exits and entries into the building lowers the energy requirements in a number of ways: infiltration is reduced, more efficient use of space is possible, less security lighting is required, and less heat loss/gain is experienced.

g. The building plan can have a great effect upon the amount of energy consumed by the air and water distribution systems for heating and cooling. Long duct and pipe runs require proportionately more energy to drive pumps and fans. A plan which can reduce the extent of the distribution systems leads to operating economy and energy conservation.

h. An airport terminal building, in particular, offers considerable opportunities for heat loss/gain through infiltration at door entries and at baggage loading/checking areas. Significant energy savings can be achieved by selecting a building plan which uses vestibules, double doorways, automatic doors, windbreak structures, automatic baggage claims, etc.

25. BUILDING ENVELOPE. The building envelope, consisting of walls, windows, roofs, and floor surfaces, directly affects the heating and cooling peak demands and is a major determinant of the yearly energy consumed in maintaining the building thermal environment. The following properties should be considered in designing an energy efficient building envelope.

a. Walls.

(1) Walls of large mass have high thermal inertia which modifies the effect of heat transmission by delay and by damping. For example, a wall of high thermal inertia--100 pounds per square foot (500 kg/sq.m or greater)--subjected to solar radiation for 1 hour will absorb the heat at its outside surface and transfer it to its interior over a time period as long as 6 hours. Conversely, a wall of small mass--less than 25 pounds per square foot (125 kg/sq.m)--may take as little as 2 hours to accomplish this heat transfer. This property is important in areas subject to long, cold winters or long, hot summers with extreme peak temperatures and large diurnal swings.

(2) Building opaque walls should be designed with materials highly resistant to heat transfer. Select materials and insulation to provide a minimum "U" value consistent with the climatic conditions that the building will likely encounter. The term "U" denotes the overall coefficient of heat transfer expressed in Btu's per hour per square foot per degree Fahrenheit. The lower the "U" value, the higher the resistance to heat transfer. Table 2 provides some recommended minimum "U" values for varying climatic conditions.

Table 2. Recommended Minimum "U" Values--Opaque Walls.

Heating Degree-Days	Recommended Min. "U" Value	Heating Degree-Days	Recommended Min. "U" Value
1000	0.40	6000	0.15
2000	0.30	7000	0.15
3000	0.30	8000	0.10
4000	0.20	9000	0.10
5000	0.20		

(3) The location of insulation in a wall section can affect energy consumption, although not usually as much as the type of insulation which is used. (The thermal value of different insulating materials varies considerably.) From a theoretical point of view, the best location for insulation is on the exterior of the wall section, thus permitting the mass of the building to act as thermal storage to dampen the effects of diurnal weather variations and indoor occupied-unoccupied temperature cycles. If possible, insulation should not only be located on the exterior of a wall section but also on the exterior of the structure itself so as to reduce air leakage through construction joints and to reduce heat loss by eliminating the effect of thermal bridging between the wall and concrete or steel structure members.

(4) Insulation should be protected from moisture since its insulating value decreases sharply when wet or damp. Types that have low water permeability and which dry out quickly and return to their original thermal performance should be considered.

(5) Wall textures, canopies, and carefully selected and located vegetation can shade and maintain a film of still air on building surfaces to reduce heat loss and heat gain.

(6) On exterior wall surfaces, light colors decrease and dark colors increase solar heat gain. In most cases, a dark-colored north wall and a light-colored east and west wall will be the most energy conserving. In hot climates, all walls (and roofs) of light color and high reflectivity are best. The color of the wall has relatively little effect on energy consumption when used on exterior walls of low "U" values and high thermal mass.

(7) It is recommended that a vapor barrier be provided on the interior surface of exterior walls to prevent condensation.

(8) Burying the building or parts of the building by use of earth berms minimizes both solar gain and air infiltration caused by the effect of the wind as well as the heat loss or gain due to air temperatures. Berms are most effective in areas of high winds, extreme solar gains, and extreme hot or cold temperatures.

b. Windows, Glass Paneling, and Doors. For aesthetic and architectural effect, many airport terminal buildings are designed with windows, glass exterior walls, doors, and openings far in excess of any requirement for natural light, ventilation, or even view. These excesses increase energy consumption extensively. They result in heavier heating loads during cold weather because of the increased loss of heat through the glass walls, etc., and the increased infiltration of the colder outside air. In hot weather, they produce heavier air conditioning loads due to increased solar radiation gain and infiltration of hot outside air. They can also cause considerable discomfort to passengers and employees, causing overheating in summer, cold down-drafts in winter, and visual glare during certain periods of the day. Elimination of all windows, on the other hand, would exclude desirable natural light, eliminate enjoyable views, and create a claustrophobic effect. Selective use of glass and openings can have very beneficial results without being very energy wasteful. Factors that should be considered include the following:

(1) Heat transmission is much greater through glass than through most opaque walls. "U" values for opague walls can be reduced to 0.06 or less, whereas single glass has a "U" value of about 1.13, double glass 0.58 to 0.69, and triple glass 0.36 to 0.47.

(2) Heat loss/gain from glass walls and windows can be minimized by considering the use of one or more of the following: providing very low ratio of glass wall/window area to opaque area; double or triple glazing; operable thermal shutters and external/internal shading devices; the avoidance of window/doorframes that form a thermal heat transfer bridge between interior and exterior; and use of reflective and special purpose glass. NOTE: Mirrored glass used extensively on exterior building walls can act like a solid metal wall reflecting electronic signals from navigation and communications equipment causing erroneous readings. When facing aircraft operational areas, this material can also create unwanted and potentially unsafe reflections and glare affecting a pilot's vision. When such use is considered, selective orientation and/or adequate shielding can prevent these adverse effects from occurring.

(3) Climatic conditions and solar exposures should be considered in locating windows, skylights, openings, etc. For example, to minimize heat gain in hot climates, south walls should have a low glass/opaque area ratio. On the other hand, in cold climates, this same ratio should be low on north walls to minimize heat losses.

(4) An operable thermal barrier installed over windows at night and weekends to reduce heat loss or heat gain when the building is unoccupied will considerably reduce the yearly heating and cooling demands. It will also mean less operating time for the heating and cooling equipment.

(5) Solar controls for glazed areas, such as canopies, drapery, or operable blinds, can conserve energy by controlling solar radiation input. These devices are most effective when located on the exterior of the building, particularly those having a movable design. Fixed solar fins and overhangs which eliminate direct solar penetration in the summertime also block out some of the solar rays in the late spring and early fall which can be useful for heating. Their

effectiveness can be improved if they are designed specifically for each facade, since time and duration of solar radiation varies with the sun's altitude and azimuth. Horizontal shading is particularly effective on southern exposures. If overhangs, however, are not extended far enough beyond the edges of the windows, considerable effectiveness can be lost by permitting solar impingement during a good part of the day. On east and west walls, combinations of vertical and horizontal sun baffles are suggested.

(6) Infiltration is the air passage through cracks, joints, pores, and openings in building construction. The amount of air infiltration depends upon the intensity of wind velocities and temperatures, character of cracks, and the relationship of windward and leeward openings, among other things. Infiltration can account for a substantial part of the air conditioning and heating loads in a building and can be decreased by using one or more of the following measures: employing impermeable exterior surface materials; keeping cracks around doors, windows, etc., to a minimum; installing permanently sealed windows; providing weather stripping around all external doors; and putting sealing gaskets and tight locking devices on operable windows.

c. Roofs.

(1) Heat transmissions through the roof can be reduced by use of one or more of the following: insulation; roof sprays; roof sod; location of equipment rooms on roof; and double roof design with ventilation spaces between.

(2) To increase heat gain due to solar radiation on roofs, use a dark colored finish having high absorptivity; conversely, in hot climates, finish roofs with light colored surfaces having high reflectivity.

(3) Provide solar shading for the roof in the same areas where similar solar control is desirable for glazing and walls.

(4) Skylights, when used, should be double or triple glazed, particularly in areas where heat loss is a significant factor.

d. Floors.

(1) As with the walls and roof, floors having undersides exposed to the exterior (i.e., over unheated garages, overhangs, etc.) can significantly affect the heating and cooling loads of a building. The larger the exposed surface area in proportion to the perimeter skin, the greater this effect. It is, however, not usually as significant as the roof, which is directly exposed to the sun. The fewer floor levels a building has, the greater the effect that the exposed floor will have on the sizing of the building's heating and cooling equipment.

(2) Insulation used with floors exposed to the exterior is often located on the interior surface. However, as with other exterior skins, placing the insulation on the outside surface is more effective. Use of batt insulation hidden by a suspended ceiling in the exposed area should be considered.

(3) In cold or cool climates, perimeter insulation under floor slabs and adjacent to grade beams is recommended.

(4) A floor covering, such as carpeting, can improve the insulating qualities of the floor slab and can improve the absorption or reflection of light to achieve the desired effect.

SECTION 2. LIGHTING.

26. GENERAL. A lot of energy can be saved in lighting. The following paragraphs provide some recommendations for reducing existing and new lighting levels, improving the efficiency of lamps and fixtures, and avoiding energy waste in lighting design and installation.

27. REDUCE ILLUMINATION LEVELS. Uniform lighting in airport terminals and other buildings may simplify design problems but it wastes energy. Lighting levels maintained for the most critical tasks waste energy when other less critical tasks do not require the same amount of illumination. Each distinct functional area within the building and the discrete tasks which occur within them should be lighted only to the level and quality required for each task, and only for the timespan during which the task occurs. Tasks requiring quite different lighting levels are frequently intermixed more than need be. Lighting efficiency can be enhanced if like visual tasks are grouped together. If this is not possible, the simple expedient of using portable lights in key locations can be a practical and relatively inexpensive answer. For existing buildings designed with uniform lighting, conversion to selective lighting can be achieved rather inexpensively through a number of actions including: removal of excess lamps; and installation of multilevel ballasts or dimmers. Table 3 provides some recommended illumination levels for various building localities.

Table 3. Recommended Illumination Levels.

Area	Design Level (Footcandles)	Design Range (Footcandles)
Waiting Rooms and Lounge Areas	15	10 - 18
Service or Public Areas	15	12 - 18
Conference Rooms	30	25 - 35
Circulation Areas Between Work Stations	30	24 - 36
Corridors, Lobbies, and Exits	15	10 - 18
Cafeteria, Snack Bars	30	20 - 40
Kitchens	50	30 - 70
Work Stations	50	30 - 60
Office Areas	60	40 - 90
Mechanial Rooms	10	5 - 15
Storage Areas	10	5 - 15
Toilets	20	15 - 30

28. IMPROVING LIGHTING SYSTEM OPERATIONS.

a. Switches. Considerable energy savings can be achieved simply by turning off lights when not in use. However, to turn off lights requires a switch and many buildings have entire floors or wings controlled by a single switch. Fine tuning of the lighting system requires a capacity to switch off lights in unoccupied spaces and areas. Although not always practical, the ultimate in flexibility consists of an individual switch at each light fixture. The next choice (from an energy standpoint) is the use of switches that control several fixtures that illuminate a localized area. If such switches are not a part of the original design, they can be installed. Some suggestions regarding these installations include:

(1) Many types of surface-mounted flat-ribbon conductors are available for installation in existing spaces; these can be installed with a minimum dislocation of existing wiring or damage to interior decorations.

(2) New switches should be located near doors, if possible, where they will be most convenient for occupant use. Switches at inconvenient locations will not be used. If switches are group-mounted, each switch should be labeled to indicate the area that it controls.

(3) Time switches should be provided for areas which are commonly used for short periods and in which lighting is inadvertently but frequently left on. At a predetermined time after the switch has been turned on, it will automatically shut off; if the area is to be used for a long period of time, the switch can be manually overridden.

(4) For large areas, remote-control lighting contactors or lighting relays (to operate multiple circuits) can be added above the ceiling or at the lighting distribution panel. Remote switches can be either line or low voltage.

(5) Site lighting and parking lot lighting can be controlled with time switches or with photoelectric cells. The latter are also effective in controlling light fixtures in the interior perimeters of the building where daylight is sufficient for illumination.

(6) Frequency-controlled relays can be added at individual fixtures or at the circuit breakers which control a number of fixtures. The relay is controlled by an activator which superimposes a special command frequency over the existing wiring system. The activator can be controlled by remote-control or local switch, timeclock, or photoelectric switch. One activator can control lights which are on any number of separate circuits.

(7) Switching is important in conserving the energy in the lighting system, but switching is worthless if it is not used. Perhaps more than with any other aspect of energy conservation, with switching the attitude of the people using the building makes the difference. Switching off lights when leaving a room or space has to become a habit. The posting of turn-off-the-lights instructions and reminders should help make it happen.

b. Pilot Lights. Pilot lights should be installed outside all rooms that are infrequently used and where there is no other external indication that lights have been left on. Pilot lights should also be added to indicate when loads are energized at remote locations such as site lighting, sign lighting, snow melting, ovens, mechanical spaces, and penthouses. Pilot lights can be surface-mounted or recessed and can usually be added in parallel with the circuit or the load to be monitored. To conserve energy, neon-type pilot lights are better than incandescent lights.

c. Cleaning. The value of cleanliness is obvious. Fixtures should be cleaned, at the least, at relamping, for if relamping and cleaning are combined the additional labor required is very small. In extremely dirty atmospheres, however, the fixtures should be cleaned between lamp replacements as well.

d. Relamping. The value of relamping before burnout is not so obvious as the value of cleanliness but is well worth consideration. There is added expense for the lamps themselves, but with new lamps there will be an improved value in lumens per watt of lighting. In addition, with group relamping there will be some reduction on labor cost per light in comparison with on-call-at-burnout replacement. This is an interesting problem in cost effectiveness, but generally a group replacement plan at 80 percent of the rated hours of fluorescent lamps is advisable. If lamps are kept in use until burnout and fixtures are dirty, a revised relamping schedule and cleaning may actually allow a reduction in lamp wattage in each fixture without any reduction in lighting level.

29. IMPROVE SPACE CONDITIONS.

a. Reflecting Wall Surfaces. Much of the light from a fixture is reflected from room surfaces and furnishings before it reaches a visual task. Reflected light will have less value, or strength, than direct light, by the amount absorbed by the walls and other reflecting surfaces. The larger a room and the lighter the room finishes, the lower will be the amount of reflected light absorbed and the greater will be the actual task illumination. If wall, ceiling, and floor reflectances of 50-30-20 are increased to 80-60-40, the lighting level will go up by about 15 percent; if reflectances of 50-10-10 are increased to 80-60-40, the lighting level will go up by about 35 percent.

b. Ceiling Height. An additional option can be explored in improving task illumination by actually lowering the entire ceiling including the lights or lowering the mounting heights of the fixtures alone. In the average room, the walls absorb much of the light before it reaches the task, even if the walls are white. When the mounting height of the light is lowered, less light is reflected by the walls and more is placed on the task. If ceilings are already 10 feet or less, there is little to be gained and this option is inappropriate.

c. Pendant Lighting. Use of pendant lighting can be very productive. For existing buildings, conversion to this type of lighting fixture most likely will be an extreme move and too costly for the anticipated benefits to be gained. With pendant lighting in high spaces, the merit in lowering the light level is greater. Increased glare from lowered lights is, however, a factor that must be taken into consideration.

30. IMPROVE LAMP AND FIXTURE EFFICACY.

a. The efficacy of lamps is measured in lumens per watt (lm/W). Selecting lamps with higher lumen-per-watt output permits the removal of some lamps or the raising of light levels. More efficient lamps will impose smaller heat loads on the air-conditioning system in summer months, whereas in winter, any heat lost by a reduction in lighting wattage can usually be supplied more efficiently by the heating system. The extreme variation in efficacy of lamps is clearly shown in table 4 which was developed from information contained in the 5th Edition of the Illuminating Engineer Society (IES) Handbook.

Table 4. Characteristics of Typical Lamps.

Classification	Typical Size and Type	Color Index (CRI)	Range of Life, Hrs.	Efficacy (1) Lumens/Watt
Incandescent	40W, General Service	92	1,000-1,500	11
Incandescent	100W, General Service	89	750-1,000	22
Fluorescent	20W, 24-in.	55-75	9,000-15,000	50
Fluorescent	40W, 48-in.	55-75	12,000-20,000	70
Fluorescent	75W, 96-in.	55-75	12,000-20,000	73
High Intensity Discharge	400W, Coated Mercury	47-51	16,000-24,000	50
High Intensity Discharge	400W, Metal Halide	53-72	12,000-18,000	77
High Intensity Discharge	400W, High Pres. Sodium	21	12,000-18,000	100

(1) Initial output including power required for auxiliaries.

b. A first reading would indicate that all fixtures should be relamped for sodium vapor, but good lighting design and use of higher-efficiency lamps are not always compatible for all functions. A high-pressure sodium vapor lamp is a very bright, concentrated light source and is difficult to use in, say, a low-ceiling lounge without excessive glare. Fluorescent lamps with outputs up to 84 lm/W are more appropriate for such use.

c. Aesthetics, size, efficacy, color, initial cost of operation and maintenance all help to determine choice of lamps. Energy conservation in lighting is not synonymous with a sacrifice in quality; good lighting is obtained by an intelligent application of many interrelated factors. Correctly applied, energy conservation can increase the quality of lighting while reducing operating costs.

d. The ballast for electrical discharge lights requires wattage in addition to that needed for the lamps. Ballasts, like lamps, vary in efficacy. When the standard ballasts in existing systems fail or must be replaced, it is possible to save 2 to 4 watts per ballast by using a line of premium-priced ballasts. For instance, in an installation of 1000 two-lamp 40-W fluorescent luminaires, each ordinary ballast consumes 12 to 14 watts, amounting to an annual energy consumption of 24,000 to 28,000 kWh in buildings operating 2000 hours per year. A more efficient ballast which consumes 10 watts will use only 20,000 kWh annually, for a savings of 4000 to 8000 kWh a year.

e. Most fluorescent installations currently in use operate at the power supply frequency of 60 Hz. Higher efficacy with fluorescent lighting is possible with higher frequencies. When remodeling or expanding all or a portion of a building with fluorescent lighting (or when changing from incandescent lighting to fluorescent), consider high-frequency lighting. Existing fixtures can be modified to be used with high-frequency systems, and new fixtures are available with high-frequency ballasts. Though conversion costs are quite high, high-frequency system lamps produce about 10 percent more lumens per watt. Thus fewer lighting fixtures are required, and ballasts can be located out of the air-conditioned area. The higher frequencies most commonly considered are 400, 800, and 3000 Hz. Future installations may include 30,000 Hz; the higher the frequency, the greater the advantage.

f. Lamp and fixture efficacies together determine the quantity of light transmitted into a space for each watt of power consumed. When a more efficient lamp source suits the application, but conversion of the fixture to handle this source is not possible, consider replacing the fixture itself. Select the most efficient lamp for the application, then choose a fixture with good performance and reasonable brightness control.

g. Many fixtures have lenses that diffuse an intense light source, or improve distribution of the light, but in so doing sharply reduce the fixture efficacy. If lenses are not really required for glare control or distribution, they can simply be removed. This is often the case in corridors, toilets, and storage rooms. If lenses are inefficient but nonetheless necessary, they can be replaced with more efficient types. The relative efficiency and general characteristics of the most common lenses are as follows:

(1) Prismatic Plastic and Glass. Generally the most efficient of its type for the degree of glare control. Best suited for all finished office space applications. A nonyellowing type of plastic should be selected.

(2) Plastic Louver. Very inefficient. Should be used only where extreme dirt buildup is a problem. About 33 percent less efficient than prismatic plastic.

(3) Parabolic Wedge Louver. Very inefficient in transmitting light but provides excellent visual comfort and glare control. This lens should be used for special effects for very low ceiling brightness and minimum distraction.

(4) Fresnel-Type Lens. The most efficient of its type, best suited for all recessed fixture applications.

(5) Opal or White Diffusers. Much less efficient in delivering light to a work surface. Generally 30 percent less efficient than Fresnel-type lens. Good light diffusion but may become a source of glare.

31. NATURAL LIGHTING. Energy savings by the use of natural lighting can easily be offset by additional heat gains and losses associated with the glass walls and windows required. Design with natural lighting is difficult as daylight varies with time of day, time of year, location, and weather. There is also the additional problem of glare. Nevertheless, its use should not be totally discounted. To obtain the best of natural light requires common sense and the use of some controls. Design for daylighting should consider the following:

a. Daylighting does not reduce the amount of artificial light that must be installed in a building. It does, however, reduce the total energy consumption for lighting of those areas which receive sufficient natural light to allow the lights to be turned off for part of the occupied hours.

b. If daylight is available, less electric light will be necessary for general illumination or specific task lighting. But people, however well intentioned with respect to energy conservation, are not wholly reliable in turning out unnecessary lights. Therefore, a particularly useful investment is a photosensitive switch which can turn off outer banks of light when sufficient daylight is available.

c. Electric lighting should be layered away from sources of daylight so that each layer, or bank of lighting, can be switched independently. As the sun sets, or the fog rolls in, lights can be turned on in banks toward the outside windows; as the sun rises, or the sky clears, banks of lights can be switched off away from the natural light.

d. In winter, direct sunlight can be welcome additional heat if it is not borne by any one person, that is, if it can be allowed to fall on circulation or unoccupied space. Otherwise the direct sun must be screened and only the indirect light from the sky or reflected sun should be allowed into the space.

e. In summer and in hot climates, if direct sunlight is not properly controlled, the heat gain imposed on the cooling system can easily outweigh savings from turning off electric lights. On east and west exposures, it is difficult to screen the direct sun without also sharply diminishing the amount of useful daylight, but it can be done through the use of adjustable window controls that in winter allow the maximum benefit for both heating and lighting and in summer keep the direct sun out but let daylight in.

f. The penetration of daylight into any space is in part dependent on the color and texture of exterior materials near the window. The actual illumination at a task location can be materially improved by increasing the reflectances of nearby exterior surfaces. In light wells and courts, walls should be painted light colors. White stone or concrete at the base of a building will bounce light into ground floor ceilings.

g. Skylights are windows in the roof. They have the potential for admitting much light (as much as 40 W equivalent fluorescent lighting per square foot of skylight), but it is difficult to control. An operable louver installed above the skylight is one solution to this problem. If, when the direct sun is admitted, glare is a problem, the skylight can be painted a diffusing white. A better solution is to add a prismatic lens at the base of the skylight.

h. Blinds and drapes which are already installed should be adjusted through the day to make the most effective use of daylight. In this instance, the user of the space is the expert.

SECTION 3. POWER.

32. GENERAL. The amount of electric power used within a building depends upon:

a. The demands of the systems which use power to supply the building load;

b. The power losses of the conversion and distribution systems which supply those loads; and

c. The characteristics of the electric service and distribution systems.

Reducing power demands of motors for mechanical systems and lighting provides the major opportunities to conserve electrical energy in a building. There are, however, additional measures which can result in significant energy savings. Some of these opportunities are discussed below.

33. REDUCE ENERGY REQUIREMENTS FOR ELEVATORS, ESCALATORS, AND MECHANICAL WALKWAYS. Elevators, escalators, and moving walkways are used to a great extent in airport terminal buildings to move people from one part of the building to another. During peak periods, it is important that this equipment be operating at peak output to assure the rapid movement of people between aircraft gates and between processing points and the aircraft and vice versa. However, at many airports, there are long periods at night and other times of day when the traffic is extremely light and this equipment can be slowed down and/or reduced in use without detrimental effect in the movement of people.

34. REDUCE ENERGY CONSUMPTION FOR EQUIPMENT AND MACHINES. Most airport buildings contain many electrically-driven machines which are left switched on and idling, even though used only for short periods of time or when the building is occupied. Often they are not for operational purposes but simply remain on because no one thought to turn them off. Baggage conveyor belts, motorized carts, business machines, etc., are some examples of the type of equipment most often neglected in this manner. An inventory of all these machines and their time of use will provide means of identifying those devices in which energy savings are possible. Installation of automatic timing devices and shutoffs will in many cases correct this problem. Promotion of employee awareness programs should also produce good results.

35. REDUCE TRANSFORMER LOSSES.

a. Transformers reduce transmission and distribution voltage to equipment operating voltage. Heat generation and dissipation, due to electrical resistance in the transformer, result in electrical energy losses. Even when equipment served by the transformer is inoperative, some energy is lost unless primary power to the transformer is switched off.

b. When the transformer serves loads which are not required for relatively extensive periods of time, complete disconnection from the primary power may be feasible. Take care, however, to avoid disconnecting transformers that feed clocks, heating control circuits, fire alarms, or critical computer processing equipment. Potential savings are 3 to 4 watts per kilovolt-ampere (kVA).

c. If a new transformer is required, select one with a high-efficiency rating.

36. IMPROVE EFFICIENCY OF MOTORS.

a. Because original calculations of loads are usually conservative, and often after loads have been reduced through conservation measures, most motors will be oversized for the load they are serving. If the ratio of the motor's load to its horsepower rating is small, the power factor will be low, and the motor will operate inefficiently.

b. Motors that are not loaded to at least 60 percent of their potential are relatively inefficient and reduce the power factor of the entire electrical system. Underloaded motors can be exchanged with others in the building to achieve as close to full loading on each motor as possible.

c. If a motor needs replacing, a new motor more closely matched to the load should be selected. For equipment which cycles on and off at short intervals, heat buildup is a less critical problem than in other cases; the motor service factor establishes the maximum overload possible without exceeding the motor's temperature rating. Use this information (available through the manufacturer) when in the process of exchanging and interchanging motors. For cycling equipment, select smaller motors, rated slightly below maximum load requirements, and allow some overloading to occur.

SECTION 4. HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC) SYSTEMS.

37. GENERAL. It takes energy to move energy for heating and cooling. However, energy can be saved if the efficiencies of both the conversion and distribution elements of these systems are improved. Some suggestions for such improvements are discussed in this section.

38. SYSTEM DESIGN. In system selection and design, the focus must be on the total system and its energy efficiency. Some considerations involving initial HVAC system design include:

a. Certain areas of the building, for instance computer and electronic equipment rooms, may require cooling whereas the rest of the building requires heating. If the floor plan does not permit this excess heat to flow to the rest of the building, heat storage systems employing heat pumps can be used to transfer heat from one location to another or store the heat for later use.

b. Increasing air duct and pipe sizes reduces pressure and consequently necessitates smaller fans and pumps thereby cutting energy consumption.

c. Most equipment has best energy efficiency at full load and, therefore, should be sized to match the requirements without excessive safety factors.

d. A combination of two or more HVAC systems can be used in the same building--each system having the best energy use for its particular area.

e. Dual duct and multizone systems mix hot and cold air and are, therefore, not energy conservative. The former, when designed with separate air handling units for each exposure and with adequate control systems are more efficient than multizone systems served from one air handling unit. However, multizone systems are now available which have individual heating and cooling coils for each zone supply duct, and the supply air is heated or cooled only to the degree required to meet the zone load. These units use far less energy than units with common coils.

f. Variable-air-volume (VAV) systems include an air-handling unit which supplies heated or cooled air at constant temperatures (which can be reset) to VAV boxes for each zone. Variable-air-volume boxes regulate the quantity rather than the temperature of the air. Varying air quantity with the appropriate supply temperature is one of the most efficient modes of operation in terms of energy usage. The fan should be run at full volume only when all VAV dampers are fully opened.

g. Electric heating, generally in the form of electric radiation or electric reheat coils, consumes more raw source energy than well-adjusted fossil fuel systems. However, heat pumps, particularly air-to-air or water-to-water units use one-half to one-third the amount of electricity as electric heating equipment to produce the same number of Btu's.

h. Where high pressure steam is available, a life-cycle cost analysis for the given heating and cooling load profile should be made to consider the alternatives of using the steam directly in high pressure, steam absorption units; in steam turbine drive for compressor motors and then in low-pressure steam absorption units; or in steam turbine drive from compressor motors and then using the exhaust steam for other subsystems.

i. High-pressure steam absorption units are now available that require about 40 percent less energy for the same refrigeration effect than conventional units, and thus, if the heat is also extracted from the condensate, they compare favorably with electric-drive compression units for energy efficiency.

j. In many localized areas in a building, e.g., vestibules, loading ramps, etc., energy can be saved by use of infrared or spot heat rather than heating the whole area.

k. In one-story buildings, gravity ventilators provide adequate ventilation without the need of power blowers.

l. A modular boiler system composed of multiple boiler units, each of small capacity, will increase seasonal efficiency. Each module can be fired only when required at 100 percent of its capacity, and fluctuations of load can be met by firing more or fewer boilers. A small-capacity unit has low thermal inertia (giving rapid response and low heat-up and cool-down losses) and can be operated at maximum efficiency or can be turned off.

39. EQUIPMENT PURCHASE. Special care should be exercised in purchasing air conditioners and boilers because the energy efficiency of units of similar output but different make can vary from 25 to 45 percent. The higher efficiency units tend to have higher initial costs though.

40. REDUCE FLOW RESISTANCE IN DUCT AND PIPING SYSTEMS. The total resistance to flow in duct and piping systems is the sum of the various resistances of the individual parts of the circuit. Straight lengths of duct and pipe generally offer little or no opportunity for resistance reductions; the potential for other items is even more substantial. Some of these are discussed below.

a. Filters. The resistance to airflow through filters is a function of filter construction, type of medium, area of medium per unit volume of air passed through it, and the dirt load at any given time. In general, resistance to airflow increases with filter efficiency, although there are available some high efficiency filters that have a low resistance. Filter installations should be checked to determine whether an alternative type of filter will adequately meet building needs at operating costs sufficiently reduced to make such a replacement program cost effective. In any case, filters should be inspected frequently to prevent excessive dirt accumulation. Inexpensive devices (manometers) are commercially available to measure static pressure drop across each air filter or filter bank in the system. When dirt accumulation causes a difference in pressure across the filter to reach a predetermined level, the filter should be cleaned or replaced. If the building or building complex contains many air systems, an alarm program can be used in conjunction with the manometers to report dirty filter conditions. Such an alarm can be an element of a central control system described in paragraph 45.

b. Coils. When the cooling medium is chilled water and the heating medium is hot water, it may be possible to remove the heating coil and repipe the cooling coil to provide both heating and cooling (though not simultaneously). Eliminating the heating coil will reduce the system resistance and allow savings in fan horsepower. A side benefit of using the cooling coil for both heating and cooling is that the extra heat transfer surface of the cooling coil provides opportunities to lower the hot-water temperatures and use low-grade waste heat for heating.

c. Duct Fittings and Shapes. High resistance to airflow caused by duct fittings on the inlet and discharge side of fans can be reduced by modifying the shape of the fitting. Where space permits, abrupt changes in sections of duct work where velocities exceed 2000 ft/min (610 m/min) should be replaced with long taper fittings. Turning vanes should be installed in square bends.

d. Balancing Ventilation System. Correct volumes at each grille or register are achieved by adjusting dampers in low-resistance branches until all branches are of a resistance equal to the index run. When systems are initially started, all dampers are often closed more than they need be, adding unnecessary resistance. It is also common practice to reduce fan volume by closing down dampers on the fan inlet or outlet rather than by reducing fan speed. In either of these situations, the system should be rebalanced.

e. Pipe Strainers/Filters. In piping systems, strainers are often dirty and the filtration media are often rusty, corroded, and deformed. These should be cleaned or replaced on a regular maintenance schedule.

f. Heat Exchangers. Heat exchangers have a high resistance to flow and are prone to fouling by scale deposits and dirt. A program of maintenance and water treatment for heat exchangers should be based on regular observations of pressure drop and temperature differentials.

g. Balancing Piping System. When existing piping systems are first operated, the installing contractors usually balance flows by trial and error. Often they close balancing valves to a greater extent than is needed, imposing extra head on the pump. To reduce resistance to flow, rebalance the system by first opening fully the balancing valve on the index circuit and the pump discharge valve, and remove any orifice plates from the pump circuit. Then adjust the circuit balancing valve on the next longest circuit, then the next, progressing to the shortest circuit, to achieve proportional flow rates. This process is one of trial and error, nevertheless, two or three successive adjustments of the whole system will normally achieve a good balance.

41. REDUCE VOLUME OF FLOW. When the heating, cooling, or ventilation loads are less than the original design, the flow rate through these systems may be reduced by lowering the speed of the fans or pumps. By reducing the volume of air in a system by 10 percent, energy savings of about 27 percent can be achieved.

42. REDUCE THERMAL LOSSES. Energy losses from piping and duct systems occur in the form of heat gain to cooled air or chilled water and heat loss from hot air, water, or steam systems. Though ductwork for both heating and cooling is commonly insulated, warm-air ducts alone are often installed without insulation and are typically routed from the equipment room through unoccupied spaces, shafts, and ceiling voids where their heat loss is unproductive. Although the temperature difference between duct and ambient air is relatively small, heat loss in long duct runs can be significant. Of equal importance is the temperature drop of supply air that accompanies heat loss. In long duct runs serving many rooms in one zone, the temperature of the supply air will be lower in the last room than in the first. The tendency in this case is to heat the last room to comfort conditions, resulting in overheating in each preceding room with consequent additional waste of energy over and above the heat loss in the duct. Energy losses can be minimized by insulating the ducts with commercially available material. Insulation for piping is very important and if existing insulation is bad, it should be immediately repaired or replaced.

43. IMPROVE BOILER EFFICIENCY. Although there are many types and sizes of boilers, furnaces, and burners in use today, all have certain common characteristics, and similar techniques can be used to improve their efficiency and conserve energy. The following are some suggested actions:

a. Air Leaks and Controls. Air is used to provide the necessary oxygen for burning and must be supplied in excess of the theoretical requirements to ensure complete combustion. The quality of air that just gives complete combustion is the optimum amount. Any reduction in the optimum air quantity prevents complete combustion and wastes energy, but it can be adequately controlled. Any increase over the optimum will reduce not the efficiency of combustion itself, but rather the rate of heat transfer to the boiler or furnace, and will increase the heat lost out of the chimney. Measures should be taken to prevent leaks of uncontrolled air into the combustion chamber.

b. Cleaning. Burners should be cleaned and adjusted each year. The condition of the heat transfer surface directly affects heat transfer from the combustion chamber. The fireside of the heat transfer surface must be clean and free from soot or other deposits, and the airside and waterside must be clean and free of scale deposits. In the case of steam boilers, once the waterside of the boiler is clean, correct water treatment and blowdown should be instituted to maintain optimum heat transfer conditions. On oil and gas burners, special care should be taken to regularly clean dirty oil nozzles and fouled gas parts.

c. Flue-Gas Analyzes. The efficient combustion of fuel in a boiler requires an optimum fuel/air ratio providing for a percentage of total air sufficient to ensure complete combustion of the fuel without overdiluting the mixture and thereby lowering boiler burner efficiency. Excess air through a boiler can waste 10 to 30 percent of the fuel burned. Optimum combustion efficiency varies continuously with changing loads and stack draft, and it can be closely controlled only through analysis of flue gases. Knowledge of flue-gas temperature and either flue gas carbon dioxide (CO_2) or oxygen (O_2) content is required to permit continuous adjustment of fuel/air ratios. Indicators are available which continuously measure CO_2 and stack temperature and give a direct reading of boiler efficiency. These indicators provide boiler operators with the requisite information for manual adjustment of fuel/air ratios and are suitable for smaller installations or for situations in which money for capital improvements is limited. A more accurate measure of efficiency, however, is obtained by analysis of oxygen content. If both are available, the cross-checking of O_2 and CO_2 concentrations is useful in judging burner performance.

d. Isolation of Off-Line Boilers. Light heating loads on a multiple-boiler installation are often met by one boiler on line with the remaining boilers idling on standby. Idling boilers consume energy to meet standby losses which can be further aggravated by a continuous induced flow of air through them into the stack and up the chimney. Unless a boiler is scheduled for imminent use to meet an expected increase in load, it should be secured and isolated from the heating system by closing valves and from the stack and chimney by closing dampers. Large boilers can be fitted with bypass valves and regulating orifices to allow a minimum flow through the boilers to keep them warm and to avoid thermal stress when they are brought on-line again.

e. Preheating Combustion Air. Preheated primary and secondary combustion air will reduce the cooling effect when the air enters the combustion chamber and will increase the efficiency of the boiler. In most boiler rooms, air is heated incidentally by hot boiler and pipe surfaces and rises to collect below the ceiling. This air can be used directly as preheated combustion air by ducting it down to the firing level and directing it into the primary and secondary air inlets. Waste heat reclaimed from boiler stacks and blowdown or condensate hot wells can also be used to preheat combustion air. Heat exchange from flue gases to combustion air may be made directly using static tubular or plate exchangers or rotary exchangers. Heat exchange may also be made indirectly through runaround coils in the stack and combustion air duct.

f. Preheating Oil. Waste heat from sources such as flue gases, condensate, and hot wells, or from solar energy, may also be used to preheat oil either in the storage tanks (low-sulfur oil requires continuous heating anyway to prevent wax deposits) or at the burner nozzle.

44. IMPROVE AIR-CONDITIONING SYSTEM EFFICIENCY. The performance or seasonal efficiency of an air-conditioning system can be increased by changing the mode of operation and operating conditions which are the rule rather than the exception in virtually all buildings and by improving maintenance and service procedures. Some suggestions for doing so are as follows:

a. Cleaning Cooling Towers and Condenser Units. Because water is constantly being evaporated in cooling towers, total dissolved solids in the condenser water system increase scale at the spray nozzles and on the baffles and fill. Scale formation on the spray nozzles not only reduces the quantity of water flow, but will also inhibit the fine atomized spray necessary for evaporation. Correct rates of blowdown will hold total dissolved solids in the condenser water system to a tolerable level, and correct water treatment will prevent scaling both in the tower and in the refrigeration machine. Also, nozzles can also be clogged with algae growth, particularly if the cooling tower is located in strong sunshine. If the cooling tower is contaminated with algae or bacterial slime, it should be thoroughly cleaned with chlorine and flushed through to remove all deposits; this should be followed with periodic treatments with algicides.

b. Relocating Condensers. Because it forms part of the refrigerant system, the air-cooled condenser (with its connecting pipework) imposes a resistance to refrigerant flow and increases the pressure at which the compressor must operate. Condensers are frequently installed in locations remote from the refrigeration compressor, but often they can be easily relocated to reduce the length of connecting pipework. Any reduction in pipework length will decrease the friction loss and increase the efficiency of the refrigeration machines.

c. Leaks. Leaks from the refrigerant high-pressure side of the air-conditioning system will reduce the refrigerant charge and, hence, the refrigeration effect that can be obtained for a given power input. Leaks on the low-pressure refrigerant side (if the pressure is subatmospheric) will allow the entry of air into the refrigerant system. Air is composed of noncondensable gases and will reduce both the rate of heat transfer of the condenser and evaporator and, again, the refrigeration effect available for a given power input. Common sources of leaks include shaft seals, inlet guide vane seals, valves, and pipe fittings.

d. Compressors. Compressor drive trains, if poorly maintained, can absorb as much as 15 percent of the total energy input into the compressor. Speed-reducing gear boxes should be routinely examined for quality and quantity of lubricating oil, gear backlash and wear, thrust-bearing condition, and main-bearing condition. Belt drives should be examined for correct tension. Where multiple belts are used, all belts should be replaced at the same time, or different tensions will result, causing a loss of transmission efficiency.

45. INSTALL CENTRAL CONTROL SYSTEM. A central control system provides the engineer and energy management team with a means of constant surveillance of the building and helps in making efficient and effective use of physical plant systems and personnel. It can accomplish a number of tasks: monitor all systems for operating conditions, including fire alarm and security devices; optimize the operation of all systems to obtain maximum performance for minimum energy expenditure; and limit peak electrical demand values by predicting loading trends and by shedding nonessential services according to programmed priorities. Central control systems vary from the relatively simple to the very complex. The system should be tailored to the requirements of the building and the operations to be controlled. If money for investment is limited, attention should first be given to those functions which will show the quickest and greatest return in energy saved. Provisions should be made, however, for expansion of system hardware and software capacity as investment money might later permit. An initial system, for instance, may be limited to a console and central processor unit with one single printer output and may be programmed to perform only start-stop and simple reset functions and to report alarms. Optimization of system operation and load shedding in this case would be achieved manually at the central console on the basis of decisions made by the operating staff and would involve overriding the programmed start-stop times and reset points for the various systems.

CHAPTER 4. ALTERNATE ENERGY SOURCES

46. GENERAL. Alternate energy sources, for the purpose of this discussion, are defined as energy alternatives to the burning of fossil fuels and to the use of nuclear fission for generating electricity. Included in this category are the combustion of methane gas produced from liquid and solid waste, hydropower, the combustion of wood, the rare cases of on-site geothermal or tidal power, the use of wind, and the collection and use of solar energy. Solar energy is the only alternate energy source discussed below because it alone has the potential for immediate and widespread use in airport buildings. Also discussed below is the "total energy system." Although not strictly speaking a alternate energy system, it is an energy-conserving concept applicable to some airport buildings.

47. SOLAR ENERGY. The primary purpose for collection of solar energy is for use as a fuel supplement in the form of light and heat. Direct conversion of solar energy in solar cells to generate electricity as used in the space program is not presently economically feasible for commercial use in buildings. Significant present-day applications of solar energy include domestic hot water heating, space heating, space cooling, and dehumidification. The following two paragraphs provide a brief discussion of the technology involved in solar collection and storage and in the major applications for airport buildings.

48. SOLAR COLLECTION SYSTEMS. A solar collection system includes a device for absorbing the sun's energies, pipes or ducts for transporting collected energy, a storage unit, and a system of controls to operate and make use of the collected or stored energy.

a. Collectors. Flat-plate collectors are used to absorb both diffuse and direct radiation. For building application, they are simpler than focusing or concentrating collectors that are capable of collecting only direct radiation and hence, must track the sun. The usual collector consists of a cover plate made of one or two layers of glass having a high transmissivity and coated with a flat black paint; a metal plate, generally made of copper, aluminum, or steel; a tubing or fluid passage array that is integrated with the collector plate; a heat transfer fluid, usually distilled or deionized water; and insulation covering the back of the plate. As solar radiation strikes the blackened collector plate causing it to heat, the collector plate, being a good absorber, conversely is a good emitter. However, the radiation emitted from the collector plate is in the infrared portion of the spectrum. Normal window glass is opaque to long wavelength radiation, hence forming a heat trap. In a sense, the glass acts as a one-way valve for short wavelength radiation. Once the collector has been heated, this heat is extracted through a heat transfer fluid which can be either a gas in an air-heating collector or a liquid which is more typical with current state-of-the-art. The liquid, in most cases water (with additives), flows through a tubing array and then into a header system which will transfer the heat either to the building heating system directly or to a storage container. Air-heating collectors are most suitable for space heating applications alone (no cooling) and are particularly useful for warming makeup air or outdoor air for ventilation.

b. Storage. The most practical storage system with liquid collectors is hot water in metal or concrete tanks. From 2 to 5 gallons of storage are required per square foot of collector (80 to 200 liters/sq.m). Since a supplementary heating system is required in virtually all cases, the life-cycle costs of storage volume (and space required) can be reduced by operating the supplementary backup system somewhat longer and by reducing the volume of storage. With hot-air systems, rocks can be used for heat storage in place of water. In this system, the rock bed is charged vertically with hot air from the top of the storage tank. Air from the collector to heat the building is taken also from the hot upper part of the rock bed storage. Such a system requires 2.5 times the volume of a water storage system. Most experiences to date indicate that storage capacity in excess of one to two days of heating need is not economical. Generally, an allowance of two or three gallons of water storage per square foot of collector area (80 to 120 liters/sq.m) is reasonable. A minimum of two storage tanks should be considered to permit storage of water at various temperature levels to limit degradation of high water temperature at times when there is little sun. Another storage system called latent heat storage uses phase-changing salts (salt hydrates, eutectic salts, waxes, and parafins). The system requires less volume than water for equal thermal storage. The state-of-the-art for this system is not fully matured but the potential is very good. Some of these systems are just now becoming available commercially.

c. Controls. The control system, at the least, must operate circulating pumps, divert warm water from one storage tank to another or direct to load, or operate fans in air systems to blow air through the collectors and storage tanks in response to the building load. Controls are not usually a major cost of the installation unless elaborate monitoring is required.

49. SOLAR ENERGY BUILDING APPLICATIONS.

a. Hot-Water Heating. Hot water for use in airport rest rooms, restaurants, etc., can be heated by solar water heaters that are commercially available. The components include a flat plate collector, storage tank (existing tanks can be used), piping, controls, circulating pump, and, in climates where the collector is subjected to freezing weather, a heat exchanger with a secondary pump, piping circuit, and antifreeze. For normal hot water use, approximately 1 square foot (.09 sq.m) of collector and 1 gallon (3.8 liters) of hot water storage per 16 gallons (60 liters) of hot water used per week are adequate. If kitchens or other processes require hot water at elevated temperatures, 20 to 50 percent more collector area should be provided. In most cases, it will not be economically feasible to attempt 100 percent of the hot water requirement with solar heating.

b. Space Heating. Contemporary HVAC systems using water typically operate at temperatures greater than 160 degrees F. Such temperatures are attainable with available solar collectors which use water as the transfer medium, but collector temperatures are increased, and the efficiency of the collector decreases as fluid temperatures increase. For new buildings, it is desirable to design the heating system for fluid temperatures of 100 degrees F to allow low-temperature solar collection. Solar collectors combined with existing or new heat pumps can be very effective in this regard. Low-temperature fluid delivered from the collector in cold and overcast weather can still serve as a heat source for a heat pump. The heat pump boosts the temperature to a higher level, and the useful hours of solar energy collection are substantially increased. Solar-assisted heat pump installations should be considered especially in existing buildings that are already equipped with heat pumps or with electrically driven chillers which can be converted to heat pumps.

c. Space Cooling. The common means for using solar energy for cooling are with absorption chillers. With absorption systems, solar-heated water serves as a heat source in the absorption generator. Unfortunately, larger units in excess of 100-ton capacity require 230° to 270°F for generation, and most solar collectors on the market cannot provide these temperatures for any appreciable length of time. Newer low-temperature absorption units are now available though, in limited sizes, to operate at generator temperatures as low as 175°F at peak conditions and as low as 170°F with some loss of rated capacity. Flat-plate collectors with selective surfaces and supplementary aluminized Mylar polyester film reflectors can perform at temperatures up to 220°F in some climatic zones for a sufficient number of hours per cooling season to operate such absorption units. However, there are not many areas in the country where absorption units running from solar-collected heat alone can economically supply the majority of yearly cooling requirements of a building. Vacuum-tube collectors, and a number of focusing collectors, are now commercially available and are capable of providing the higher temperatures required to operate absorption units.

d. Dehumidification. In areas where evaporative cooling is impractical because of high relative humidity, evaporative cooling combined with desiccant dehumidification can provide adequate comfort; heat from the solar collector can supplement heat from other sources to regenerate the desiccant. Since regeneration temperatures are lower than those required for absorption cooling, the collector can be operated at cooler temperatures and is thus more cost-effective.

e. Other Uses. For large heating installations using No. 6 oil, flat-plate solar collectors can be effectively used to preheat oil before combustion to increase the efficiency of combustion. The oil storage tanks can be painted black for direct heating by the sun and can be fitted with heating coils through which the heated fluid from the collector is circulated. No additional storage system is required. In like manner, the efficiency of oil or gas combustion increases as the temperature of combustion air is increased. Solar air or water collectors, without any additional storage facilities, can be used to warm air for combustion (or warm makeup air for ventilation). This is especially effective since the temperature of outdoor air in the winter may range from -30° to 50°F, and collector fluid only 20° or 25°F above outdoor air temperature can efficiently provide useful heat.

50. PASSIVE SOLAR SYSTEMS. Passive solar systems do not require solar collectors and storage tanks but simply make use of solar-oriented and energy-conserving architecture to reduce space heating requirements of buildings. In many cases, a well-designed passive system may reduce the heating requirements by over 50 percent with little or no additional construction cost. The airport terminal building in Aspen, Colorado, provides an interesting example of passive solar system use. The basic elements of the building design that combine to create energy-conservation qualities are discussed below.

a. Building Plan. The single-story, 16,800 square foot terminal building contains offices and waiting rooms designed in three building pods staggered and linked together to achieve maximum solar orientation for the south walls and to provide exterior entry spaces.

b. Beadwall. Most of the southern wall is composed of a double-glazed "beadwall." The latter is a movable insulation system in which a 3-inch-wide cavity between two transparent glazings is filled with styrofoam beads when there is no solar heat gain such as at night or during cold, cloudy days. The beadwall provides an insulating effect that is approximately equal to 3 inches of fiberglass insulation. When the cavity is empty, solar energy penetrates the building. A simple, reversible vacuum motor is used to empty or fill the wall cavity with the styrofoam beads from the bead tank storage.

c. Skylights. The roof of the building has south-facing skylights with fiberglass glazing and movable louvers. The "skylid" system is a series of insulated, aluminum-covered louvers which automatically open during periods of solar heat gain and are generally closed the remainder of the time. The louvers are balanced with a Freon canister on the exterior and interior surfaces. The canisters are connected by a copper tube, allowing the heat-sensitive Freon to flow from one to the other as it expands and contracts with small variations in temperature due to exposure of the sun's radiant energy. This weight shift automatically opens and closes the skylights.

d. Building Thermal Mass. The building is insulated to an R20 value and uses minimum window exposure on the remaining north, east, and west walls. The interior thermal mass for the terminal consists of 5-inch thick concrete floor slabs and 8-inch solid concrete block walls. These elements used for thermal mass absorb the solar heat during sunny days and reradiate this heat into the building's interior space, particularly at night. This diminshes the need to use the conventional forced-air heating system.

e. Earth Berms. The north and east walls have small windows placed high in the walls in order to allow earth berming against the outside surface of the walls. This earth berming greatly reduces the heat loss through these walls.

f. Conventional Heating System. In the cold but sunny Aspen winter, the terminal's passive solar design provides 35 to 40 percent of the building's heating requirements. For the remainder, a conventional gas-fired, forced air system supplies the difference.

51. TOTAL ENERGY SYSTEMS. Total Energy (TE) is the name given to onsite generation of electricity if the waste heat of generation is recovered for use by the building. The lure of total energy lies in this recovered heat, since its equivalent would have to be purchased in the form of other fuels. The recovered heat can be used for heating domestic hot water, for warming outdoor ventilation air, for making steam for adsorption refrigeration, for space heating, for producing process steam, or for preheating boiler combustion air and oil. Some general characteristics of Total Energy Systems are noted below.

a. Since all TE installations require added investment, the system is economic when energy savings are sufficient to amortize both the higher capital costs and the added costs of service, maintenance, and replacement parts. Large projects with a reasonably uniform year-round load factor for all energy-consuming services (such as airport installations) lend themselves to the application of a total energy plant.

b. The most common Total Energy System consists of an electric generator driven by a turbine or an engine fueled by natural gas or oil. The exhaust gases are put through a waste heat boiler which, in turn, does the building heating or furnishes steam for absorption refrigeration equipment. Domestic hot water is generated either by the engine jacket water or from the waste heat boiler. Further refinements, such as heat pumps, can be incorporated in the flow cycle to utilize more of the waste heat and level off the electrical load.

c. TE plants can be expected to consume 25 to 40 percent less raw source energy than that required for a combination of fossil-fueled or nuclear-powered central electricity generating plants and onsite boilers.

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APPENDIX 2. COMPUTER PROGRAMS

DESIGN PROGRAMS

Type	Name	Author
Building form		
Form generation	Form Generation	University of Southern California
Shading analysis	SHADOW	University of Texas
	SUNNY	University of Texas
Solar gain analysis	SUNSET	Dubin-Mindell-Bloome
Building exterior envelope		
Glass comparison	Glass Comparison	Libbey-Owens-Ford
Building interior planning		
Optimization	ARK-2	Perry, Dean & Stewart
	B.O.P.	Skidmore, Owings & Merrill
Lighting		
Conventional	Lighting II	APEC, Consulting Engineers Council
	Lighting	Dalton, Dalton, Little & Newport
	Interior Lighting Analysis & Design	Giffels Associates, Inc.
ESI	Lighting Program	Isaac Goodbar
	Lighting Program	Illumination Computing Service
	Lighting Program	Ian Lewen
	Lumen II	Smith, Hinchman & Grylls
Daylighting	Daylighting	Libbey-Owens-Ford
Power		
Distribution network	Electrical Feeder II	APEC, Consulting Engineers Council
	Electrical Feeder Sizing	Dalton, Dalton, Little & Newport
	Three-Phase Fault Analysis	Giffels Associates, Inc.
Demand study	Electrical Demand Load Study	Giffels Associates, Inc.

DESIGN PROGRAMS (Continued)

Type	Name	Author
HVAC		
Equipment selection	HCC-III (Mini-Deck)	APEC, Consulting Engineers Council
	Equipment Selection	Carrier Air Conditioning Co.
	Equipment Selection	Trane Co.
Duct design	Duct Program	APEC, Consulting Engineers Council
	Several	Dalton, Dalton, Little & Newport
	Several	Giffels Associates, Inc.
Air-handling unit design	Fan Static Calculations	Giffels Associates, Inc.
Domestic water		
Piping design	Piping Program	APEC, Consulting Engineers Council
	Several	Dalton, Dalton, Little & Newport
	Several	Giffels Associates, Inc.
Vertical transportation		
Elevator design	Elevator Design	Dover Corporation
	Elevator Design	Otis Elevator
Operation and maintenance		
Automated control systems		Honeywell, Inc.
		Johnson Control Service
		Powers Regulator Company
		Robertshaw Controls
Solar energy systems		
Solar collector Models	Flat Plate Collector	Honeywell, Inc.
	Parabolic Trough Collector	Honeywell, Inc.
	Flat Plate Collector	Westinghouse

ENERGY USAGE PROGRAMS

Name	Author
Commercial Programs	
ECUBE	American Gas Association
HCC-111	APEC, Consulting Engineers Council
Energy Analysis	Caudill Rowlett Scott
AXCESS	Electric Energy Association
Glass Comparison	Libbey-Owens-Ford
Energy Program	MEDSI
Energy Analysis	Meriwether & Associates
Building Cost Analysis	PPG Industries
TRACE	Trane Company
Energy Program	Westinghouse Corp.
HACE	WTA Computer Services, Inc.
Research Programs (Negotiable)	
CADS	University of California at Los Angeles
SIMSHAC	Colorado State University
FINAL	Dalton, Dalton, Little & Newport
HVAC Load	Giffels Associates, Inc.
Energy Program	Honeywell, Inc.
NBSLD (Honeywell)	Honeywell, Inc.
Energy Program	University of Michigan
NBSLD	National Bureau of Standards
B.E.A.P.	Pennsylvania State University
Post Office Program	
DEROB	University of Texas
TRANSYS	University of Wisconsin
In-House Programs (Proprietary)	
Energy Program	General Electric Company
Residential and Small Commercial	Honeywell, Inc.
Energy Program	IBM

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